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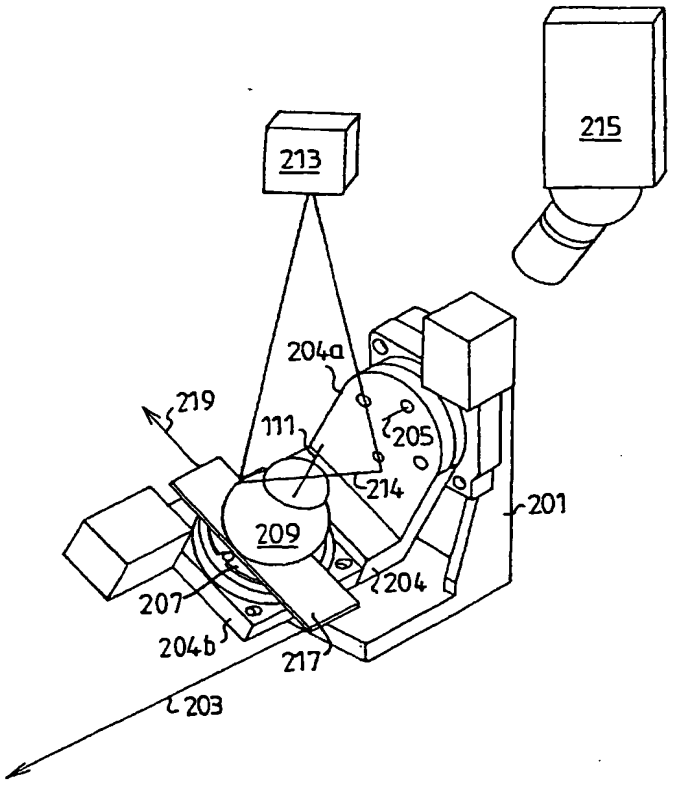
[Continued on next page]

(54) Title: METHOD AND APPARATUS FOR MEASUREMENT OF TOOTH PREPARATIONS AND THEIR DENTAL ENVIRONMENT



(57) Abstract: An apparatus for acquiring data about a dental object are disclosed, said apparatus enabling the rotation of the dental object around at least two rotational axes and the translation along at least one translation axis. Steep surfaces, i.e. surfaces at a small angle from the light source, can then be ad-justed to improve the resolution so that they can be imaged under better conditions. It is also possible to capture data near edges under good conditions. Faulty data that will inevitably be captured in some positions can then be discarded.

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Published:

— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Method and Apparatus for Measurement of Tooth Preparations and their Dental Environment

Technical Field

The present invention relates to a data acquisition apparatus according to the preamble of claims 1 and also to a method of acquiring data about the shape of a dental object and a computer program product.

Description of Related Art

Manufacturing of a tooth restoration at a dental laboratory often requires knowledge not only about the prepared tooth that is to be cured but also about the remaining teeth near it, that is, the dental environment. When working with CAD/CAM technology it is important to get the information of the dental environment into the computer system. This information is generally carried from the patient's mouth to the dental laboratory in a bite impression in silicone or some other material. This impression is used for casting replicas of the jaws using some kind of stone or plaster. The plaster model is then used to manufacture the restoration and ensure that it fits, with regard to the prepared tooth itself as well as regarding neighbours in the mesial and distal direction and teeth in the opposite jaw.

A method for doing this is known from WO98/36702, in which a line of light is projected across the tooth and used to image the profile of the tooth along the line. The unit projecting the light and the imaging unit are placed at an angle relative to each other and the surface to be imaged. The line, or the tooth, is then moved and another profile image is made. Finally, an interpolation is made between the profiles to create an image of the tooth.

The line will not be projected properly on parts that are shaded by another (protruding) part. Therefore, the apparatus of WO98/36702 is also able to rotate the tooth around an axis normal to the direction of movement, before repeating the pro-

cedure of projecting the line of light and imaging in several positions across the tooth. With this rotation overlapping data is created.

Generally, the width of the line depends on the angle between the source of light and the surface on which the light is projected. Therefore, on surfaces at a too small angle in relation to the light the line will be too wide, and the accuracy of the imaging will be low. Also, sharp edges may block part of the projected line, thus creating measurement errors.

Object of the Invention

It is an object of the present invention to provide a method and an apparatus for creation of measurement data from prepared teeth and their dental environment.

Summary of the Invention

This object is achieved according to the invention by a data acquisition apparatus for acquiring data about the shape of a dental object, said apparatus comprising an imaging device for imaging said object, and a holder device adapted to hold the dental object when it is being imaged, wherein at least a part of said holder device is rotatable about a first rotation axis, said apparatus being characterized in that said holder device is rotatable about at least a second rotation axis.

The object is also achieved by data acquisition apparatus for acquiring data about the shape of a dental object, said apparatus comprising an imaging device for imaging said object, and a holder device adapted to hold the dental object for allowing scanning of the light line to be performed over said surface, wherein at least a part of said holder device is rotatable about a first rotation axis, said apparatus being characterized in that said holder device is slideable along at least a sliding axis.

The object is also achieved by a method of acquiring data about the shape of a dental object held by a holder device, including imaging the object while performing the steps of

- turning said holder device about a first rotation axis to a first defined releasable stop
- turning said holder means about a second rotation axis to a second defined releasable stop.
- moving said laser line across said dental object while viewing it by said viewing unit and registering data regarding the shape of the dental object.
- processing the data to establish an elevation profile of said object.

The object is also achieved by a computer program product which, when run on a control system for a data acquisition apparatus comprising a holder device for an object, said holder being slideable along at least a first translation axis, and rotatable around at least a first and a second rotation axis, and an imaging device, causes the apparatus perform the following steps:

- turning said holder device about the first rotation axis to a first releasable stop,
- turning said holder means about a second rotation axis to a second defined releasable stop,
- imaging the object when the holder is fixed in said first releasable stop and said second releasable stop.

The first and second rotation axes are preferably perpendicular to each other.

With this method and apparatus it is possible to adjust steep surfaces to improve the resolution so that they can be imaged under better conditions. It is also possible to capture data near edges under good conditions. Faulty data that will inevitably be captured in some positions can then be discarded.

The second rotation axis forms an extra tilt axis, which solves the problem of generating measurement data of sufficient quality in the following two situations:

- At surfaces that are parallel or nearly parallel to the projected light, the line or lines projected on the object will be very wide, causing a poor accuracy.

- Near sharp edges only a part of the line or lines of light will be visible from the camera, while other parts will be hidden by the edge. This generates unacceptable measurement errors.

The imaging device may comprise a source of light, preferably white light, adapted to project a light line on the surface of said dental object, and a viewing unit adapted to view said light line when formed on said surface. The method then comprises the step of imaging by moving a line of light across said dental object while viewing it by a viewing unit and registering data regarding the form of the dental object.

Said holder device is preferably also slideable along a first translation axis parallel to the first rotation axis. This enables a translational movement of the object relative to the source of light.

In a preferred embodiment, the holder device comprises an object foundation rotatably mounted on a consol device and a mounting portion, the object foundation being rotatable in relation to the consol device around the first rotation axis, the consol device and the mounting portion being arranged perpendicularly to each other, and the mounting portion being rotatably mounted on the carrier around the second rotation axis.

Preferably, the holder device is provided with releasable stop means for allowing said rotation about said first rotation axis and second rotation axis, respectively, to be discontinued such that the holder device is allowed to be maintained in predetermined, discrete positions around these axes.

Suitably, said light source is adapted to emit a plane of white light.

In a preferred embodiment, the holder device can be moved along a sliding axis, the orientation of said sliding axis being dependent on the rotation angle of the holder device around at least one of the first and second axes.

This enables the scanning of large areas such as bridge preparations in one operation, which is not possible with traditional triangulation scanners.

The computer program product is preferably arranged to perform further method steps, such as causing the holder device to move along a first translation axis parallel to the first rotation axis and a sliding axis, the direction of the sliding axis depending on the rotation angle of the holder around at least one of the first and second rotation axes.

In a preferred embodiment the computer program product is further arranged to collect the data from at least one image of the line for at least one position of the object, and to process the collected data to obtain an image of the object.

Preferably, the computer program product is also arranged to discard data that is deemed as not sufficiently good.

Brief Description of the Drawings

In the following the invention will be described in more detail, by way of preferred embodiments, with reference to the appended drawings, in which:

Figure 1 illustrates the principle of a prior art system;

Figure 2 illustrates the principle of a first preferred embodiment of the invention;

Figure 3 illustrates the principle of a second preferred embodiment of the invention;

Figure 4 shows an apparatus according to the first preferred embodiment of the invention; and

Figure 5 shows an apparatus according to the second preferred embodiment of the invention.

Detailed Description of Embodiments

Figure 1 illustrates the principle of the prior art system disclosed in WO98/36702. An object to be imaged is placed in a Cartesian co-ordinate system having axes x y

and z. A laser light source 1 is used to project a line 3 of light across the object. The profile of the line is imaged using a camera 5 connected to a computer (not shown). As indicated two bold arrows 7, 9, the object can be moved relative to the light source along the x axis and rotated around the z axis, respectively. A number of line profiles, for different positions of the object, are imaged, and processed in a computer to obtain an image of the object. This imaging method is known in the art and may be used in all embodiments in this document. Other known imaging methods may be used as well, such as measurements by means of fringe scanners, or using projection of a moving point, or of several points.

Figure 2 illustrates the principle of a first preferred embodiment of the invention. The object to be imaged is placed in the same Cartesian co-ordinate system as in Figure 1, and a light source 1' emitting a plane of light is used to project a light line 3 across the object. Unlike what is disclosed in WO98/36702, the light does not have to be laser light. On the contrary, it may be advantageous to use white light because the speckle noise arising from interference and extinction of the laser light can be reduced in this way. Also the speckles that arise because of when using laser light are avoided. The line is imaged by a camera 5. As in Figure 1, the object may be moved along the x axis, as indicated by a bold arrow 7, and rotated around the z axis, as indicated by a bold arrow 9. In addition, as indicated by a third bold arrow 11, the object may also be tilted around a second rotation axis. In this way, the object can be imaged at a number of different angles with respect to the x and z axes, so that parts that cannot be seen from some angles will be properly imaged at other angles. The faulty data can then be discarded and the good data used. The selection may be carried out by determining the width of the projected line on the object. When the line is wide, the conditions for measurement are not good. Such data should therefore be discarded. In Figure 2, the second rotation axis is the x axis, but another tilt axis may be preferred.

Figure 3 illustrates the principle of a second preferred embodiment of the invention. As in Figure 2, a light source 1 projects a line 3 of light onto an object placed in a

Cartesian co-ordinate system. The profile of the line is registered by a camera 5. The object may be translated along the x axis, as represented by a bold arrow 7, rotated around the z axis, as represented by a bold arrow 9 and tilted around the x axis as represented by a bold arrow 11. In addition, the object has a further sliding axis, represented by a bold arrow 13. This sliding axis 13 is dependent on the rotational angle around the z axis and the tilt angle around the x axis.

Figure 4 shows an embodiment of an apparatus functioning as illustrated in Figure 2. A carrier 101 is slideable along a first translation axis 103. A holder 104 comprising a first plane surface 104a and a second plane surface 104b mounted perpendicularly to each other is mounted on the carrier 101 through the first plane surface 104A in such a way that it is tiltable around a tilt axis 105 which is parallel to the first translation axis 103. The second plane surface 104b supports a rotatable disk 107, arranged to support an object 109 to be measured. The rotatable disk 107 is rotatable around a first rotation axis 111 perpendicular to the second plane surface 104b. A light source 113 is arranged to project a line 114 of light on the object 109 when on the platform 101. A camera 115 is arranged to image the profile of the line of light on the object 109 when on the platform 101.

With the apparatus shown in Figure 4, the object 109 to be measured is slideable, relative to the light source, along the first translation axis 103, rotatable around the first rotation axis 111 and tiltable around the tilt axis 105.

Figure 5 shows an embodiment of an apparatus functioning as illustrated in Figure 3. As in Figure 4, a carrier 201 is slideable along a first translation axis 203. A holder 204 comprising a first plane surface 204a and a second plane surface 204b mounted perpendicularly to each other is mounted on the carrier 201 through the first plane surface 204a in such a way that it is tiltable around a tilt axis 205 which is parallel to the first translation axis 203. The second plane surface 204b supports a rotatable disk 207, arranged to support an object 209 to be measured. The rotatable disk 207 is rotatable around a first rotation axis 211 perpendicular to the second

plane surface 204b. A light source 213 is arranged to emit a plane of light, thus projecting a line 214 of light on the object 209 when on the platform 201. A camera 215 is arranged to image the profile of the line of light on the object 209 when on the platform 201. In this embodiment, a slideable support member 217 is mounted on the rotatable disk 207 in a fixed angular relationship with the rotatable disk, with respect to the first rotation axis 211, but slideable along an sliding axis 219 perpendicular to the first rotation axis 211. When the rotatable disk 207 rotates, therefore, the sliding axis 219 rotates with it.

With the apparatus shown in Figure 5, the object 209 to be measured is slideable, relative to the light source, along the first translation axis 203, rotatable around the first rotation axis 211 and tiltable around the tilt axis 205. It is also slideable along a sliding axis 219, the direction of which will depend on the rotation of the rotating disk 207 around the first rotation axis 211 and the tilting angle of the holder 204 around the tilt axis 205.

This makes the apparatus of Figure 5 particularly suitable for long irregularly shaped objects such as bridges, since it enables the scanning of an object from many different positions and angles. When single crown preparations are scanned, the cervical-occlusal axis of the tooth is positioned at the rotation centre, which means that it is possible to rotate the object and scan from different views. A preparation for a bridge has at least two portions that need to be scanned from several directions. This is enabled by the movement along the sliding axis 219.

The same possibilities will be achieved if the apparatuses of Figures 4 and 5 are modified by using a fixed carrier 101, 201 and making the holder 104, 204 slideable along the first translation axis 103, 203 with respect to the carrier.

Of course, the embodiment shown in Figure 5 may be simplified by eliminating either the tilt axis 205 or the first rotational axis 211, which would, however, result in a less flexible apparatus.

To scan an object using the apparatus according to Figure 4 or 5, a line of light is first projected on the object. The profile of the line of light on the object is then imaged in a number of combinations of positions along the first translation axis 103, 203 and around the tilt axis 105, 205 and the first rotation axis 111, 211. This is preferably done systematically, for example in the following way: First the object is held at a first rotational angle, around the first rotation axis 111, 211 and a first tilt angle, around the tilt axis 105, 205, while moving it along the first translation axis 103, 203 and taking a number of images. Next, the tilt angle and/or the rotation angle is changed, and the object is imaged again while sliding along the first translation axis 103, 203. With the apparatus of Figure 5, then, the object may be moved along the sliding axis 219 before it is again moved along the first translation axis and imaged a number of times. The number of positions in which to image the object may be determined by an operator depending on the size and complexity of the object.

Of course, the movements of the object may be made in a different order, for example, by first keeping the carrier fixed in a position along the first translation axis 103, 203 while rotating the support member 107, 207 around the first rotation axis 111, 211.

This may be determined by the operator or fixed in the system, preferably by means of a computer program. A program for controlling the movements preferably comprises functions for controlling the movements of the object to fixed positions along the first translation axis 103, 203 and the sliding axis 219 and around the first rotation axis 111, 211 and the tilt axis 105, 205, and for controlling the camera so that the light profile is imaged in appropriate positions. Such a program should also comprise functions for discarding bad measurement data and for determining how many measurements are needed, and in which positions, to achieve a good image of the object.

CLAIMS

1. A data acquisition apparatus for acquiring data about the shape of a dental object (109; 209), said apparatus comprising an imaging device for imaging said object, and a holder device (104; 204) adapted to hold the dental object when it is being imaged, wherein at least a part of said holder device is rotatable about a first rotation axis (z; 111; 211), **characterized in that** said holder device is rotatable about at least a second rotation axis (x; 105; 205).

2. A data acquisition apparatus according to claim 1, wherein said holder device is slideable along a first translation axis (103; 203).

3. A data acquisition apparatus according to claim 1 or 2, wherein said holder device comprises an object foundation (107) rotatably mounted on a consol device (104b) and a mounting portion (104a), the object foundation (107) being rotatable in relation to the consol device around the first rotation axis (111), the consol device (104b) and the mounting portion (104a) being arranged perpendicularly to each other, and the mounting portion (104a) being rotatably mounted on the carrier around the second rotation axis (105)

4. A data acquisition apparatus according to any one of the preceding claims, wherein said holder device (104; 204) is provided with releasable stop means for allowing said rotation about said first rotation axis (111; 211) to be discontinued such that the holder device is allowed to be maintained in predetermined, discrete positions.

5. A data acquisition apparatus according to any one of the preceding claims, wherein said holder device (104; 204) is provided with a releasable stop means for allowing said rotation about said second rotation axis (105; 205) to be discontinued such that the holder means is allowed to be maintained in predetermined, discrete positions.

6. A data acquisition apparatus according to any one of the claims 2-5, wherein said light source (1; 113; 213) is adapted to emit a plane of white light.

7. A data acquisition apparatus according to any one of the preceding claims, wherein said holder device (104; 204) can be translated perpendicularly to one of the axes (105, 111; 205, 211) around which rotation can be performed.

8. A data acquisition apparatus according to any one of the preceding claims, wherein said holder device (104; 204) can be moved along a sliding axis (219), the orientation of said sliding axis being dependent on the rotation angle of the holder device around at least one of the first and second axes (105, 111; 205, 211).

9. A data acquisition apparatus for acquiring data about the shape of a dental object (109; 209), said apparatus comprising an imaging device for imaging said object, and a holder device (104; 204) adapted to hold the dental object for allowing scanning of the light line to be performed over said surface, wherein at least a part of said holder device (104; 204) is rotatable about a first rotation axis (111; 211), **characterized in that** said holder device is slideable along at least a sliding axis (219).

10. An apparatus according to any one of the preceding claims, wherein the imaging device comprises comprising a source of light (1; 113; 213) adapted to project a light line (3; 114; 214) on the surface of said dental object, a viewing unit (5; 115; 215) adapted to view said light line when formed on said surface

11. A method of acquiring data about the shape of a dental object held by a holder device, including imaging the object while performing the steps of
- turning said holder device about a first rotation axis to a first defined releasable stop

- turning said holder means about a second rotation axis to a second defined releasable stop.
- moving said laser line across said dental object while viewing it by said viewing unit and registering data regarding the shape of the dental object.
- processing the data to establish an elevation profile of said object.

12. A method of acquiring data according to claim 11, including turning said holder means about said first rotation axis and said second rotation axis to a predetermined number of defined releasable stops and moving said laser line across said dental object in each of the defined releasable stops.

13. A method of acquiring data according to claim 11 or 12, further comprising the step of moving said holder along a first translation axis parallel to the first rotation axis.

14. A method of acquiring data according to any one of the claims 11-13, further comprising the step of moving said holder along a sliding axis, the direction of the sliding axis depending on the rotation angle of the holder around at least one of the first and second rotation axes.

15. A method according to any one of the claims 11-14, wherein the imaging is carried out by moving a line of light across said dental object while viewing it by a viewing unit and registering data regarding the form of the dental object.

16. A computer program product which, when run on a control system for a data acquisition apparatus comprising a holder device for an object, said holder being slideable along at least a first translation axis, and rotatable around at least a first and a second rotation axis, and an imaging device, causes the apparatus perform the following steps:

– turning said holder device about the first rotation axis to a first releasable stop,

- turning said holder means about a second rotation axis to a second defined releasable stop,
- imaging the object when the holder is fixed in said first releasable stop and said second releasable stop.

17. A computer program product according to claim 16, further arranged to cause the holder to move along a first translation axis parallel to the first rotation axis.

18. A computer program product according to claim 16 or 17, further arranged to cause the holder to move along a sliding axis, the direction of the sliding axis depending on the rotation angle of the holder around at least one of the first and second rotation axes.

19. A computer program product according to any one of the claims 16-18, further arranged to collect the data from at least one image of the line for at least one position of the object, and to process the collected data to obtain an image of the object.

20. A computer program product according to any one of the claims 16-19, further arranged to discard data that is deemed as not sufficiently good.

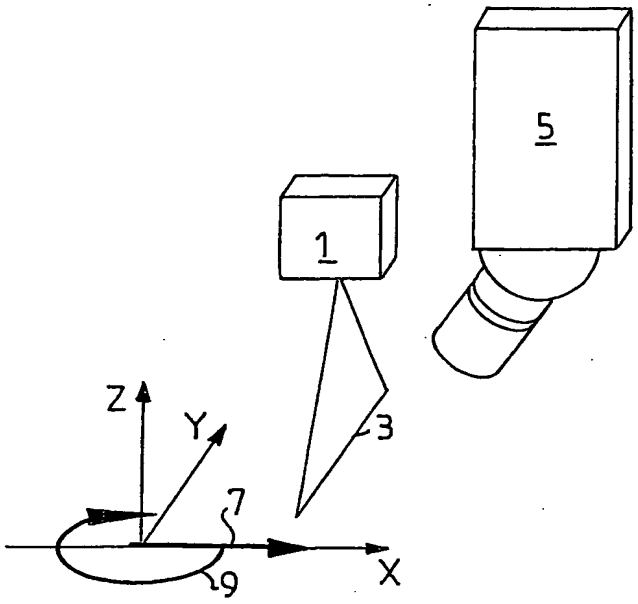

FIG.1

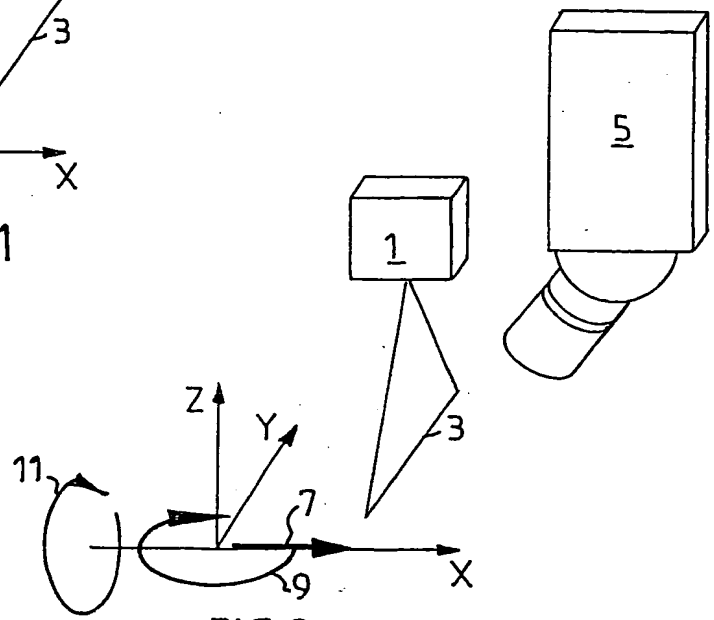

FIG.2

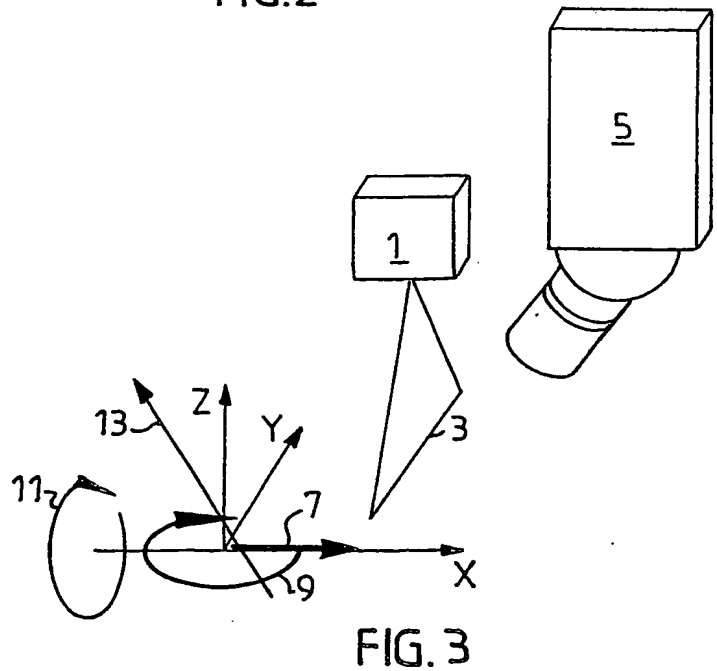

FIG. 3

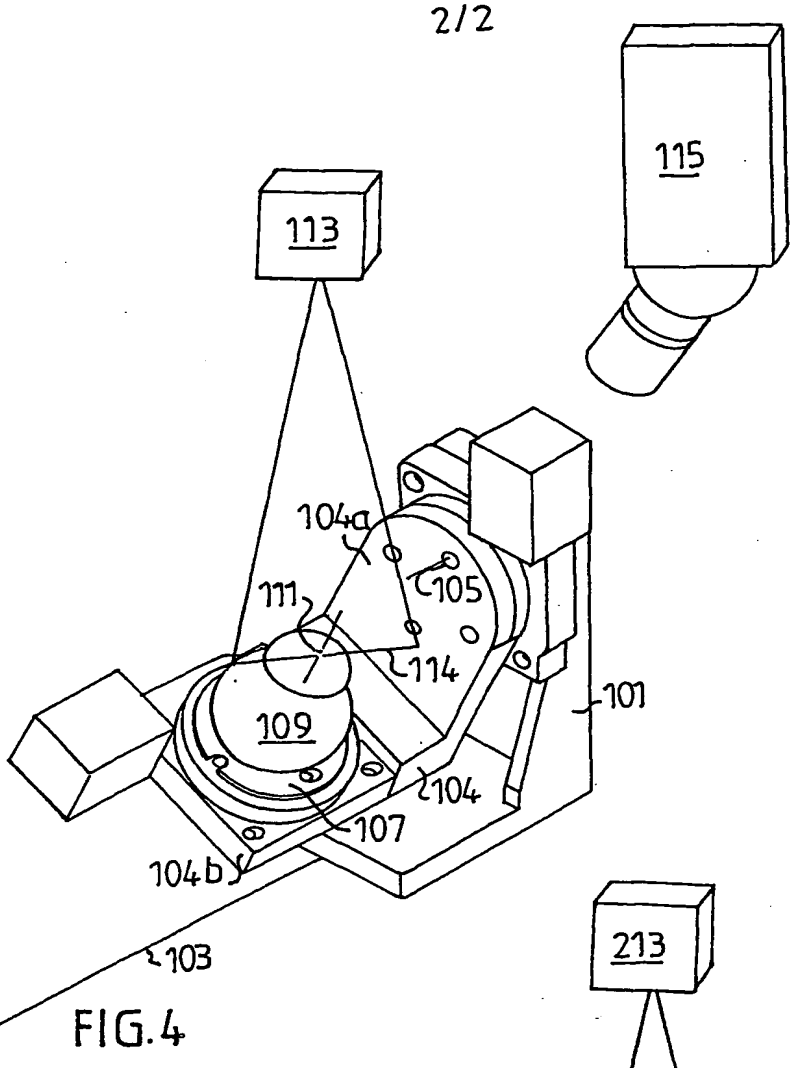
115
113
104a
111
105
114
101
109
104
107
104b
103

FIG.4

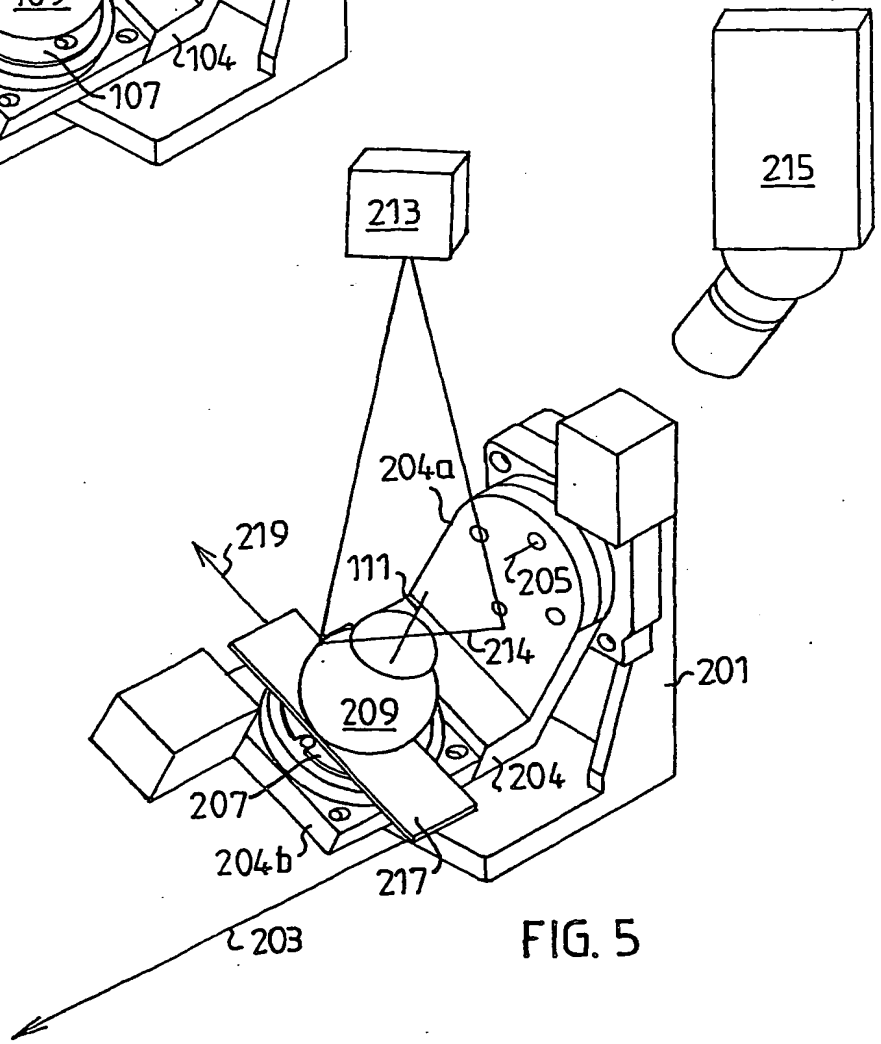
215
213
204a
219
111
205
214
201
209
204
207
204b
217
203

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 01/01984

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: A61C 13/00, G05D 1/02
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: A61C, G05D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 9836702 A1 (DENTRONIC AB), 27 August 1998 (27.08.98) --	1-20
A	WO 9962422 A1 (NOBEL BIOCARE AB), 9 December 1999 (09.12.99) --	1-20

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 January 2002	21-01-2002
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Jack Hedlund/EK Telephone No. +46 8 782 25 00

Form PCT/ISA/210 (second sheet) (July 1998)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE01/01984

Box I **Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)**

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II **Observations where unity of invention is lacking (Continuation of item 2 of first sheet)**

This International Searching Authority found multiple inventions in this international application, as follows:

I. Claims 1-8 and 11-20, directed to an apparatus comprising a rotable holder.

II. Claims 9-10, directed to an apparatus comprising a slidable holder.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☒ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 01/01984

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9836702 A1	27/08/98	AU 2656097 A	07/11/97
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		SE 9700634 A	25/08/98
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